# Development of a Towed Survey System for Deployment by the Fishing Industry


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***Abstract*** **After two generations of development, we have completed a practical digital imaging system towed by a commercial scallop fishing vessel, that delivers high resolution contiguous overlapping still images to the a computer system on the vessel bridge for storage, immediate viewing and onboard image processing. This non-invasive, high resolution survey of benthic habitat is intended to provide fisherman, fisheries managers and others with information vital to accurate scallop population density estimates and substrate characterization within surveyed areas of the continental shelf.**


## I. Introduction

Multi-species fishing in the Gulf of Maine and on Georges Bank has created a constant state of flux in the quality and diversity of habitat for sea scallops and other commercially important benthic organisms. For example, changes in habitat occur during fishing for ground fish such as cod, haddock, fluke, and flounder, and in turn sea scallop fishing alters ground fish habitat. Recent closures in ground fishing have demonstrated some plasticity in sea scallop populations; however, this plasticity is difficult to quantify accurately. In other words, it is difficult (with existing technology) to accurately measure changes in habitat structure, in the abundance and distribution of adult populations on the bottom, in settlement success, and in recruitment into commercial fishery. Reliable data on these variables is key to understanding the mechanisms of habitat stability and, consequently, it is also key to estimating the degree to which these precious resources are sustainable. One potential method for collecting such data is the visual imaging of benthic communities.

With funding from the Northeast Consortium and collaboration with researchers from National Marine Fisheries Service and the fishing industry, the Woods Hole Oceanographic Institution (WHOI) developed an imaging sled capable of carrying a camera system developed using funding from other Woods Hole development efforts. The sled, named HABCAM, for HABitat mapping CAMera was intended for use from a variety of vessels, including fishing vessels.

Our original proposal had envisioned the use of a Firewire-based continuous video camera with a frame grabbing capability. When it became apparent that industry development of firewire telemetry systems capable of use over long distances (> 10 meters) was lagging, we realized that we had to look into different camera system technology. For use on its SEABed autonomous vehicle system [1], the WHOI Deep Submergence Laboratory had integrated a Cooke Corporation Pixelfly camera into an underwater housing, and packaged its controlling PCI board and PC-104 computer for use in the vehicle. Since the goals of the SEABed effort were very similar to those of the HABCAM project, we decided to adopt the Pixelfly camera and minimize development costs while taking advantage of the imaging system similarities. The primary difference in the SEABed and HABCAM application is the interactive nature of the HABCAM system. SEABed is intended for autonomous use: images are stored during the course of the mission and not seen by human eyes until vehicle recovery. HABCAM investigators need to obtain the imagery in near-real time for decision making and processing. Development of an "attended" capability was important.

SEABed AUV code was modified to allow control and real-time telemetry to the surface, and a PC-based application was written for a topside application to control the camera and view and process the imagery.

Another key difference is imaging rate. SEABed imagery is frequently collected at quite a slow rate, while HABCAM was intended to provide contiguous coverage of the seafloor, while being towed from vessels that might not be able to easily travel at less than 3-4 knots. This necessitated rapid imagery

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collection, placing stringent requirements on both telemetry bandwidth and on strobe update rate.

The first generation of the HABCAM sled was tested on an RV Oceanus cruise in 2004 [2]. Several thousand images were collected using the pixelfly-based system. Deficiencies were found in lighting, in imaging rates, and in the ability to tow the system effectively. These deficiencies were addressed when additional funding became available from the scallop Research SetAside program of the New England Fishery Management Council, and the second generation HABCAM became operational in Fall, 2005

## II. System Description

The adoption of a new camera type simplified the HABCAM sled a great deal. By using a Camera Link interface, transmitted to the surface using gigabit Ethernet, much custom development was avoided. The gigabit Ethernet interface is also used for transmitting data from the other sensors, such as the CTD and altimeter to the surface. The overall design of the sled electronics was driven by a desire to use as much commercial equipment as possible, to increase system reliability, decrease hardware costs and to minimize hardware and software development time. Functional flexibility was built in at appropriate points. Once a few key design decisions were made, much of the equipment could be selected and purchased immediately and system integration and software development could proceed. This approach greatly shortened development time and reduced costs. While this approach may have reduced component packing efficiency and increased component count, it reduced (from the standpoint of the developers and maintainers) apparent system complexity: many of these components are already used in our offices and other vehicles.

The cable and equipment requirements controlled much of the system design. The use of a standard 0.68” electro-optical cable, identical to that used in many oceanographic vehicles (and in particular by WHOI’s suite of robotic vehicles) was an early assumption. A suite of standard oceanographic instrumentation (CTD, ADCP, altimeter, etc) was assumed. Flexibility in additional instrumentation was important. From these requirements, several initial design decisions were made.

With over 300W required at the sled (mostly for lighting), the alternatives of sending high voltage (too dangerous and difficult on a fishing vessel) or low voltage (too much cable loss) were impractical. This drove the decision to send 120Vac (which is readily available) down the wire to the sled.

Data communications to the surface is through fiber only. The early goal was to require only a single fiber for all of the image and data telemetry, since a multi-fiber slip ring has a significant cost increase over a single-fiber. This also drove the decision to use Ethernet for telemetry, since this is a medium on which it is easy to transmit a wide variety of data. Gigabit Ethernet was chosen to provide acceptable image data bandwidth.

We chose to use a single pressure housing for the camera and telemetry electronics, with additional housings for the strobes. This minimized the number of connectors, in particular, fiber penetrators. For convenience, all three copper conductors and all three fibers enter the electronics housing directly. This minimizes the complexity in an external J-box; the J-box contains only barrel connections for the copper and fibers, allowing the sled to be easily removed from the cable.

A number of identical strobe ports are provided on the electronics housing, which allows the number of strobes in use to be easily adjustable. The strobes use AC power. This saves power supply volume in the electronics housing, by using volume already available in the strobe housings.

A number of identical instrumentation ports are provided on the electronics housing, each with power and data available. This allows the instrumentation payload to be easily configurable without opening the housings.

Power available for each instrument is either 12V or 24V. Up to 10W is available at each instrument port. . DC power filters prevent noise from one instrument from potentially harming the data from another

Data for each instrument is RS232; there are a wide variety of RS232-to-Ethernet converters available in the marketplace. We use two four-port units, chosen for shape and volume considerations. RS232 optical isolation was added to all of the external data ports to minimize the likelihood of ground loops.

The primary HABCAM sensor is currently a 12-bit 1280x1024 single chip color CCD camera, made by Uniq Vision, Inc. The camera data is leaves the camera on an industry standard Camera-Link interface. A Pleora Gigabit Ethernet frame grabber connects directly to the Camera-Link output, and sends images to the surface. It also triggers the strobes and controls the camera exposure time. The use of these open standard interfaces (Camera Link and Gigabit Ethernet) means that future replacement of the camera with a different sensor becomes simple.

HABCAM uses four 20 Watt-Second Machine Vision strobes mounted in underwater housings placed radially around the camera at a distance of about 50 cm. The strobe beams are focused and collimated with fresnel lenses to provide a rectangular beam pattern approximately 1 $m^2$ at an altitude of 3 m off the bottom.

Since input power is 120Vac, it is easy to power the system on the bench, with no large power supply required. There is no sub-sea power switching; the entire system is either on or off. However, individual fusing protects each AC and DC circuit

The system includes an additional Ethernet connection, allowing easy surface access without fiber connection.

HABCAM uses only three custom electronic designs. One is a system status board, originally developed for another project. The DC filtering and RS232 isolation are accomplished on a single board. The other custom design is a small strobe trigger circuit mounted within the strobe housing.

The completed system components require a housed volume of 7" OD x 29" length for the camera/electronics housing, and 6"OD x 9.5" length for the strobes. These were packaged in 8"OD and 7"OD anodized aluminum housings respectively.

Ethernet transmission of data provided another economy in both development and operation. By their very nature, Ethernet components stand apart from each other by having independent IP numbers. This allows software development of diverse components to occur in parallel, with high likelihood that they will continue to function properly when integrated together. Also, topside data collection and analysis can be separated or combined as required, either performing many tasks on a single computer for convenience, or on separate computers for performance. Network bandwidth considerations can complicate this choice, but have not been an issue with HABCAM.

We wrote custom Windows software for displaying and logging data from all of the sensors on HABCAM. Topside network transmissions are used to route data between various pieces of software that need access to it. For example, data from the CTD and the vessel-mounted fathometer are transmitted to a "flying" display, allowing a winch operator to prevent the system from striking the seafloor. Figure 1 is a screenshot from the running system.

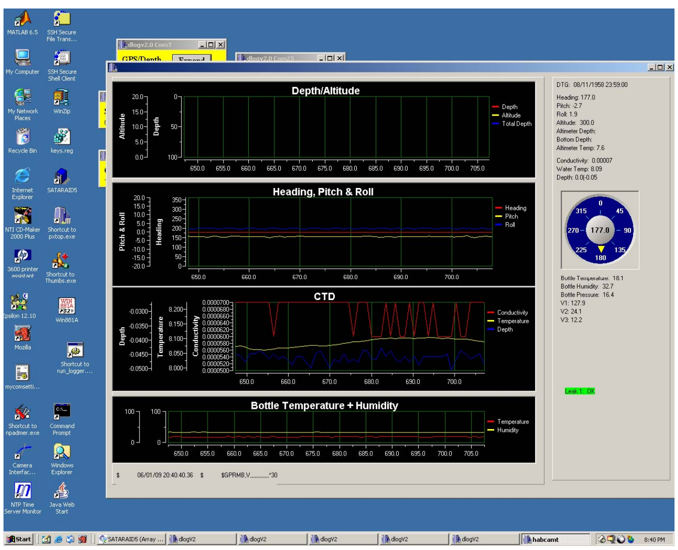


Figure 1: Screen shot from Vehicle Control Computer

We use software adapted from other development efforts at WHOI to log and display real-time imagery from the subsea camera. We log the data in a completely raw form, but in real time read new image files from the disk (thus verifying their satisfactory logging), process them, and display them to the sled operator.

The system is operated from an electro-optical cable on a deep-sea instrumentation winch. The winch is a Lebus design with a forty four inch diameter drum, twenty seven inches wide with a twenty eight inch core. The winch hydraulic motor and brake are operated using the ships hydraulics and are easily removed between science cruises with quick disconnects and rubber hose. The pay in and pay out are controlled via a winch mounted solenoid valve with a local and separate remote joy stick. There are 700 meters of .688 Rochester Dataline triple armored cable on the winch capable of a working load of 14,000 lbs and ultimate break strength of 46,000 lbs. The winch is capable of pulling 2,800 pounds and holding 10,000 pounds. The cable core consists of three individually armored/jacketed single mode fibers and three (11 AWG) copper conductors. Inside the drum of the winch is a NEMA 6P Junction box with gland fittings for the core and non-metallic LiquidTite brand tube connecting to a slip ring with single pass, single mode fiber optic rotary joint and 9 electric throughputs. On the other side of the slip ring is another length of LiquidTite tube and NEMA 6P Junction box for connecting the deck cable. A twenty eight inch diameter sheave is used on the ships A-frame for cable over boarding. The sub-sea (sled) end is mechanically terminated in a stainless steel, cone shaped spelter type termination custom made for this size cable. Socket-fast brand resin is used to form the wedge in the cone. The core of the cable is broken out at the mechanical termination and fed through a gland into an oil-filled, pressure compensated junction box where the electrical and optical connections are made. The electrical connection to the sled is a 3 pin wet-matable connector, and the fiber optic connection is a dry mate two SM fiber connector. The J-box and mechanical termination are easy to unplug and store with the winch when the system is not in use.

The entire system is designed to be portable in order to be removed when not in use and to be able to go on ships of opportunity.

## III. The Shipboard Installation

Commercial fishing vessel Kathy Marie, a 103' steel scallop trawler from New Bedford, Mass., was selected for three attributes: bridge and deck layout suitable for all necessary components, her excellent sea keeping ability, and an excellent working relationship with the owner, Captain and crew.

An A-frame with 20 ton working load was mounted on the stern with rams allowing about ~20 feet of total swing, more than adequate for the 10'l x 5'w x 4'h sled. The fibre optic winch mounted aft of the processing area about 45 feet from the stern, and was fitted with both deck and servo controls to the bridge. This configuration simplified integration with the hydraulic system, maximized fairlead to the 28" hanging block, and left the vessel's working deck clear for normal fishing operations with the imaging system fully operational. After repeated changeovers the entire system can be installed and removed in about 8 hours.

Figure 2: HABCAM being deployed from Kathy Marie

## IV. IMAGE PROCESSING

We have been developing automated classification methods to allow the large volume of data to be processed into more useful information. The associations between substrate and species in conjunction with other factors such as depth and current are used to develop maps of habitat types at multiple scales. The final goal is to make the collected data readily available to all interested parties, including fishery managers, fishermen, marine researchers, and the public via the internet in an easily navigated and readily understood manner.

There are five basic steps in processing images for characterizing habitat:

1. Image Acquisition
2. Image Correction and Enhancement
3. Target Segmentation
4. Feature Extraction
5. Target Classification.

Image acquisition of benthic habitat begins with balanced white light (for color imaging) illumination with sufficient intensity to achieve color saturation while minimizing illumination of particulates between the target plane and camera. For moving imaging platforms (4-6 kts), short exposures (2-50 usec) are critical to achieve images free from motion blur.

Image correction and enhancement involves light field balancing to remove light gradients and color correction to account for greater attenuation of light at longer wavelengths. Both processes can be accomplished through various forms of homomorphic (low pass) digital filtering and by making some assumptions or measurements about the spectral characteristics of the water. Figure 3 shows a processed image from HABCAM.

Target segmentation is perhaps the most critical and difficult process when studying benthic habitat. Typically, the background is very mottled and the organisms are by design, cryptic in nature. We are exploring new color and texture-based methods of segmenting benthic images into different homogeneous textures and identifying boundaries which separate the different regions. Feature extraction is performed in wavelet space using the Gabor coefficients calculated during the segmentation process.

To classify the different homogeneous textures, we use classifiers called Support Vector Machines (SVMs). SVMs have the advantage that they are capable of learning in high dimensional feature spaces (which ours tend to be) with a small training set. When an image mosaic is created from many sub-images, we can begin to see large-scale textures that are not readily identifiable in individual sub-images. Areas of the composite image abundant in one kind of "texture element" (whether it is a inanimate background object or an organism) will present a different large-scale texture pattern than another part of the image abundant in another texture element. Thus, mud, sand, small gravel, shell aggregations, reefs, and aggregations of cobble/boulder, scallop, or sand dollar, all present different large scale homogeneous texture patterns.

Our current benthic classification scheme includes the following:

- mud/sand without emergent biological structure
- mud/sand with emergent biological structure
- small gravel (< 2cm) without emergent/attached biological structure
- small gravel (< 2cm) with emergent/attached biological structure
- shell aggregations and/or reefs w/out emergent/attached biological structure
- shell aggregations and/or reefs with emergent/attached biological structure
- cobble/boulder without emergent/attached biological structure
- cobble/boulder with emergent/attached biological structure

Figure 3: Processed Image from HABCAM

While realizing that substrate is a continuum, we find that there are qualitative differences between habitats of mud and sand and the species that live there. Accordingly we seek to differentiate these bottom types and the associated biota. The categories listed here are segmented using the approach described above and displayed by pseudo coloring the original mosaic as a function of texture type. Associations with specific targets (e.g., larval and juvenile fish, echinoderms, hydrozoans) and texture category are made through discriminate analysis. Inclusion of diverse habitats in the analysis allow for more robust training of the SVMs, providing information about the greatest number of environments immediately useful to fishery managers and for future study by benthic habitat researchers. The techniques described here may be used in a variety of habitats both benthic and pelagic, in stereo imaging systems, or wherever difficult background lighting situations necessitate the need for advanced image processing [3].

## V. Results

HABCAM is being used on the F/V Kathy Marie to survey scallop populations along the northeast coast in several regions including: the Nantucket Lightship Closed Area, Western Great South Channel, and Elephant Trunk Area off of New Jersey.

Five separate imaging efforts have been conducted to date, with two integrated into normal fishing operations. In this latter case enough scallops are brought on deck for the crew to process for the duration of expected camera operations. The camera is then set out and survey conducted. Image processing can occur while fishing operations are in progress. In all about 1 million images representing 1.5 TB of data have been collected to date.

## VI. Acknowledgements

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